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● *Paper*

PLUTONIUM, Am, Cm AND Sr IN DUCKS MAINTAINED ON RADIOACTIVE LEACHING PONDS IN SOUTHEASTERN IDAHO

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Abstract*—Concentrations of ^{90}Sr, ^{238}Pu, $^{239,240}Pu$, ^{241}Am, ^{242}Cm and ^{244}Cm were determined in tissues of mallard ducks (*Anas platyrhynchos*) maintained for 43–145 d on radioactive leaching ponds in southeastern Idaho. Highest concentrations of transuranics occurred in the gastrointestinal tract, followed closely by feathers. Approximately 75%, 18%, 6% and 1% of the total transuranic activity in tissues analyzed were associated with the bone, feathers, GI tract and liver, respectively. Concentrations in GI tracts were similar to concentrations in vegetation and insects in the littoral area of the ponds. The calculated total dose rate to the ducks from both ^{90}Sr and the transuranic nuclides was 0.69 mGy d^{-1} (69 mrad d^{-1}), of which 99% was to the bone. The potential effective dose equivalent to a human consuming the entire muscle and liver mass of one experimental duck with average nuclide concentrations was 0.46 μSv (0.046 mrem). Based upon average concentrations in experimental ducks and on surveys of wild waterfowl using this area, a conservative estimate of transuranic activity exported by wild ducks using the ponds during one year was 11.3 kBq (305 nCi). Similarly, the total amount of ^{90}Sr exported in muscle, bone and lung of wild ducks in one year was 2.5 MBq (68.7 μCi).

INTRODUCTION

THE USE of radioactive leaching ponds by birds and their subsequent radionuclide concentrations have been reported (Willard 1960, Brisbin et al. 1974, Straney et al. 1975, Domby et al. 1977, Cadwell et al. 1979, Halford et al. 1981). At the Idaho National Engineering Laboratory (INEL) in southeastern Idaho, up to 29 γ-emitting radionuclides have been detected in tissues from waterfowl visiting radioactive liquid waste leaching ponds (Halford et al. 1981). These same ponds contain ^{90}Sr and the transuranic radionuclides ^{238}Pu, $^{239,240}Pu$, ^{241}Am, ^{242}Cm and ^{244}Cm. Waste ponds containing transuranic activity previously or currently exist at Rocky Flats, Savannah River Plant, Oak Ridge National Laboratory, Hanford and the Idaho National Engineering Laboratory (Emery et al. 1978). However, data on Pu concentrations in waterfowl at the Hanford Site are the only published information available on transuranics in waterfowl (Emery et al. 1978).

Previous studies concentrated primarily on γ-emitting nuclides because of their concentrations in tissues consumed by man. However, the bone-seeking nuclides may be important in terms of accumulation in tissues, dose to waterfowl and subsequent export from pond systems. In addition, no data are available on concentrations in waterfowl using ponds contaminated with up to five transuranic radionuclides and ^{90}Sr. The purposes of this study were (1) to document transuranic and ^{90}Sr concentrations in waterfowl maintained on these leaching ponds, (2) to establish radiation doses to the waterfowl as a result of transuranic and ^{90}Sr contamination, (3) to estimate the potential radiation doses to humans who might eat waterfowl that have visited these ponds and (4) to estimate the annual transuranic and ^{90}Sr activity potentially exported by wild ducks.

STUDY AREA

The study was conducted at the Test Reactor Area (TRA) radioactive leaching ponds at the INEL in southeastern Idaho. These ponds have been used for disposal of liquid radioactive waste from three experimental reactors. The leaching pond complex consists of three ponds which were excavated in gravely alluvium in 1952. 1957

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and 1964. A 1.1-m high wire fence surrounding the three ponds enclosed a total area of 3.0×10^4 m^2. At the time of this study, the 1952 and 1957 ponds constituted a continuous 8.2×10^3 m^2 body of water with a mean depth of 3 m. The coarsely grained sediments, gravel and stones of these pond bottoms were covered with a mat of periphyton, comprised primarily of diatoms, throughout the year (Halford et al. 1982). The 1964 pond was partially covered by shallow water forming a marshy area of approximately 130 m^2 and a dry pond basin of about 800 m^2. Aquatic and littoral vegetation associated with disturbed sites has invaded the area (Halford et al. 1982). Limnological parameters from the 1952/1957 ponds have been reported by Kuzo et al. (1983). Although the range of summer temperatures observed (16.0–22.5°C) and the dissolved O (7.1–10.8 ppm) were not unusual for ponds of this size, the low conductivity (100–180 μS cm^{-1}) and marked fluctuations in pH (7–10) were probably influenced by input from TRA facility processes.

The concentrations of γ-emitting radionuclides in the waste water were generally less than the U. S. Department of Energy (DOE) concentration guides in effect at that time (U. S. DOE 1981) for liquid effluents released to a controlled area. In addition to activation and fission products, the liquid waste contained the transuranic radionuclides, ^{238}Pu, ^{239,240}Pu, ^{241}Am, ^{242}Cm, and ^{244}Cm. The general characterization and description of the γ-emitting nuclide input to the ponds have been previously described (Halford et al. 1982, Halford et al. 1983, Kuzo et al. 1983, Halford and Markham 1984). However, quantities of transuranics disposed in the ponds are unknown.

Previous studies have documented the transuranium concentrations in some TRA pond components. Kuzo et al. (1978, 1983) reported concentrations of ^{238}Pu, ^{239,240}Pu, ^{241}Am, ^{242}Cm and ^{244}Cm in pelagic and benthic components of the ponds from the summer of 1976, 1977 and 1979. A qualitative examination of the data showed the concentrations in selected components to be similar among the three years. The average results for 1979 (adapted from data in Kuzo et al. 1983) are presented in Table 1 for those pond components relevant to uptake by ducks. In addition, the concentrations of these [illegible] nuclides in littoral area vegetation and in aquatic in[illegible] from the littoral areas in 1976 and 1977 (Kuzo et al. 1[illegible] fall between the concentrations for plankton and periphyton shown in Table 1.

MATERIALS AND METHODS

As part of concurrent studies on radiation doses to ducks (Halford et al. 1982) and elimination rates of γ-emitting radionuclides from ducks (Halford et al. 1983), commercially raised adult mallard ducks (*Anas platyrhynchos*) were purchased in September 1977. The ducks were wing-clipped, placed in a holding pen and given water and a mixture of oats, barley and wheat *ad libitum* for a period of one month. Then 14 ducks were banded, weighed and released to the TRA ponds. The ducks were fed a mixture of oats, barley and wheat as a dietary supplement while on the ponds since it was thought that sufficient natural food did not exist in the ponds. This supplementation was not considered unrealistic because wild ducks use these ponds as a resting area (Halford et al. 1981) and probably leave daily to feed in other areas.

Seven of the ducks were taken from the ponds 43, 75 or 145 d after being released to the ponds, immediately sacrificed and bone, gastrointestinal (GI), muscle, lung, liver, and feather tissue samples collected. Seven other ducks were taken from the ponds on 68, 75 or 145 d after release and placed in metabolic cages. The ducks [illegible] removed at different time periods as part of an exp[illegible] mental design of a γ-emitting nuclide study in ducks that was conducted simultaneously (Halford et al. 1983). Care and feeding of the ducks while in the cages have been previously described (Halford et al. 1983). After 51 d in the cages, the ducks were sacrificed and bone, liver and lung tissues were collected, dried and submitted to a commercial laboratory (Environmental Analysis Laboratories, Richmond, CA) for ^{90}Sr and transuranic nuclide analyses. Bone samples consisted of both humeri and both femurs from each duck. Quality control samples were spiked with known amounts of radionuclides and were submitted with the experimental samples.

Table 1. Average concentrations (Bq g^{-1}) of transuranic radionuclides in selected components from the Test Reactor Area leaching ponds, summer 1979, (N = 15).

Isotope	Filtered Water (10^{-3})	Plankton (10^{-1})	Periphyton (10^{0})	Sediments (10^{-1})
^{238}Pu	6.5 ± 0.8	5.2 ± 4.4	14.7 ± 3.1	4.9 ± 2.0
^{239}Pu	1.3 ± 1.8	3.5 ± 7.4	5.1 ± 1.6	1.2 ± 0.8
^{241}Am	4.3 ± 1.3	3.0 ± 2.9	3.9 ± 0.9	0.9 ± 0.4
^{242}Cm	4.8 ± 1.8	1.2 ± 0.3	1.1 ± 0.3	0.2 ± 0.1
^{244}Cm	7.4 ± 2.2	4.1 ± 2.4	6.6 ± 2.0	1.5 ± 0.4

Table 2. Measured analysis of spiked duck tissue quality control samples.

Tissue	Concentration (mBq g^{-1}) of Spike (Ratio: Laboratory Result/Spike)				
	^{238}Pu	$^{239,240}Pu$	^{241}Am	^{244}Cm	^{90}Sr
Muscle	0.70 (0.85)	1.37 (0.85)	0.947 (0.73)	0.858 (1.03)	139 (.98)
GI	410 (1.05)	599 (2.69)	392 (1.35)	330 (0.93)	NA
Bone	21000 (0.79)	27000 (0.82)	511000 (1.07)	3650000 (0.90)	807000 (0.72)
Liver	7.40 (1.18)	5.9 (1.14)	8.9 (1.04)	7.0 (1.00)	192 (0.97)
Lung	8.5 (0.58)	6.7 (0.57)	10 (5.93)	8.5 (0.81)	170 (0.62)

NA = No analysis

Control ducks were collected 50 km northeast of TRA. Bone, liver and lung tissues were collected from each duck and submitted with the experimental duck tissues to the commercial laboratory for analyses. Bone tissues from some control ducks were analyzed by the Radiological and Environmental Sciences Laboratory. Minimum detectable concentrations ($p \leq 0.05$) were approximately 0.075–0.30 mBq g^{-1} ($2–8 \times 10^{-6}$ nCi g^{-1}) dry weight for each radionuclide.

For calculations of total body burden in individual ducks and for dose calculations, wet weight to dry weight ratios and dry weights of individual tissues derived from mallard ducks‡ (Johnson and Hansen 1979) were used. Percent dry weights were 28, 25, 79, 68, 27 and 22% for muscle, GI, feathers, bone, liver and lungs, respectively. Total dry weights per duck were 93 g, 11 g, 66 g, 55 g, 8.4 g and 3.2 g for muscle, GI, feathers, bone, liver and lungs, respectively. Dry weights of lungs and GI tracts were determined from our samples.

Potential dose equivalent received by hunters consuming duck muscle and/or liver was calculated by:

$$H_T = \sum^{i} (DCF_{T,i})(C_i)(DF)(r), \quad \text{and} \qquad (1)$$

$$H_E = \sum^{T} W_T H_T, \qquad (2)$$

where H_T = committed dose equivalent (Sv) to tissue T, DCF = dose conversion factor expressing the 50-y committed dose equivalent (Sv) to tissue T from ingestion of 1 Bq of radionuclide i (ICRP 1979), C_i = concentration of radionuclide i in duck muscle or liver (Bq g^{-1} dry weight), DF = dry weight fraction of duck muscle or liver (g dry weight g^{-1} wet weight), r = g (wet weight) of duck muscle or liver consumed, H_E = effective dose equivalent (Sv), and W_T = risk weighting factor for tissue T (ICRP 1977).

We assumed that one hunter consumed the entire muscle and liver mass of one duck, and that there was no biological elimination of radionuclides from these duck tissues after leaving the pond and before being consumed. For dose calculations, we assumed that muscle comprised 25% of live duck weight (Halford et al. 1981), which averaged 1328 g, and that the average wet weight of liver was 31 g (Whyte and Bolen 1985).

The dose rate to the experimental ducks from radionuclides in their tissues was calculated as follows:

$$\text{Dose rate (Gy d}^{-1}) = \sum^{i}\sum^{T} (C_{i,T})(DF_T)(E)1.38 \times 10^{-5}, \qquad (3)$$

where $C_{i,T}$ = concentration of radionuclide i in tissue T (Bq g^{-1} dry weight), E = energy absorbed per radioactive decay event (MeV/disintegration), and 1.38×10^{-5} = (1 disintegration/s Bq)(1.6×10^{-10} Gy g MeV^{-1})(86400 s d^{-1}).

The energy and intensity of radioactive decay events were taken from International Commission on Radiological Protection (1983). At least 99% of the radioactive decay energy from the transuranic radionuclides comes from α and α-recoil radiations. Thus, all the α decay energy was assumed to be dissipated in the source organ. Strontium-90 and its radioactive decay product ^{90}Y decay by the emission of β particles. Most of the dose comes from the higher energy β particles of ^{90}Y (0.935 MeV, average). A β particle with this energy would travel about 0.4 cm in soft tissue and 0.2 cm in bone. Thus, it was conservatively assumed that all β particle energy is deposited in the duck tissues of interest (muscle, bone, liver and lung).

RESULTS

Quality control analyses, that is the ratio of results for analyses of spiked samples to the spike concentration for ^{238}Pu, $^{239,240}Pu$, ^{241}Am and ^{244}Cm, averaged 1.09 ± 0.46 (SD) for all tissues except lungs (Table 2). The results for lungs were probably not as good because of the smaller mass of the lungs. Results of ^{90}Sr analyses for four tissues were consistently lower than the spike concentrations (ratio: 0.82 ± 0.18).

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Table 3. Concentrations of transuranic radionuclides and ^{90}Sr in tissues of mallard ducks ($N = 7$) maintained on Test Reactor Area Ponds for 43–145 d.

Tissue	mBq g^{-1} (dry) (x 27 = fCi g^{-1})					
	^{238}Pu	$^{239,240}Pu$	^{241}Am	^{242}Cm	^{244}Cm	^{90}Sr
Muscle						
$\bar{X} \pm SD$	BDC (3)*	BDC (2)	BDC (0)	BDC (0)	BDC (0)	78 ± 63
Range	BDC – 0.20	BDC – 0.17	BDC	BDC	BDC	35 – 185
Bone						
$\bar{X} \pm SD$	0.41 ± 0.27	0.13 ± 0.04	0.19 ± 0.17	0.08 ± 0.10	0.22 ± 0.09	62,900 ± 48,100
Range	0.24 – 0.89	0.085 – 0.19	BDC – 0.52	BDC – 0.2	0.08 – 0.34	22,100 – 141,000
GI						
$\bar{X} \pm SD$	51 ± 28	11.4 ± 7.4	5.8 ± 5.5	2.1 ± 2.0	11 ± 12	NA
Range	0.44 – 106.9	4.70 – 26.3	1.9 – 17.8	0.70 – 6.4	2.5 – 38.1	
Feathers						
$\bar{X} \pm SD$	22 ± 13	5.3 ± 3.4	4.2 ± 2.6	1.9 ± 1.1	7.4 ± 5.4	NA
Range	5.92 – 42.6	2.4 – 11.9	1.7 – 9.2	1.0 – 3.9	2.4 – 18.2	
Liver						
$\bar{X} \pm SD$	14 ± 13	3.1 ± 3.0	1.8 ± 2.0	BDC (0)	0.78 ± 0.74	569 ± 1110
Range	1.6 – 34.8	0.3 – 7.5	BDC – 5.9	BDC	BDC – 2.1	56.2 – 3070
Lung						
$\bar{X} \pm SD$	0.63 ± 0.15	BDC (2)	BDC (1)	BDC (0)	BDC (2)	360 ± 290
Range	BDC – 1.0	BDC – 2.0	BDC – 1.6	BDC	BDC – 1.2	92 – 850

BDC = Below detectable concentration
NA = No analysis.
*( ) = Number above detectable concentration.

Concentrations in muscle and lung tissues from TRA ducks were below the minimum detectable concentrations for all transuranic radionuclides (Tables 3, 4). The highest concentrations occurred in the gastrointestinal tract, followed closely by feathers. Detectable concentrations of ^{238}Pu, $^{239,240}Pu$, ^{241}Am and ^{244}Cm occurred in both liver and bone tissues while ^{242}Cm was detected only in bone tissues. Strontium-90 concentrations were highest in bone, followed by liver and lungs. Muscle tissues had the lo concentrations of ^{90}Sr.

Transuranic radionuclides were below detectable concentrations in lung and muscle tissues from the control ducks (Table 5). Control transuranic bone concentrations from the commercial laboratory analyses were slightly above detectable concentrations. However, transuranic nuclides were not detectable in bone samples taken from

Table 4. Concentrations of transuranic radionuclides and ^{90}Sr in tissues of mallard ducks ($N = 7$) maintained on Test Reactor Area Ponds for 68–145 days then removed for 51 d.

	mBq g^{-1} (dry) (x 27 = fCi g^{-1})					
	^{238}Pu	$^{239,240}Pu$	^{241}Am	^{242}Cm	^{244}Cm	^{90}Sr
Muscle						
$\bar{X} \pm SD$	NA	NA	NA	NA	NA	4.4 ± 1.9
Range						2.2 – 8.1
Bone*						
$\bar{X} \pm SD$	1.1 ± 0.6	1.1 ± 0.8	42 ± 85	BDC (1)#	29 ± 58	20700 ± 5900
Range	0.41 – 20.7	0.2 – 2.0	1.9 – 215	BDC – 2.1	1.4 – 148	13700 – 31800
Liver						
$\bar{X} \pm SD$	4.0 ± 2.5	0.89 ± 0.60	0.44 ± 0.30	BDC (2)	0.26 ± 0.19	NA
Range	2.0 – 9.4	0.4 – 2.1	0.04 – 0.93	BDC – 2.2	0.03 – 0.52	
Lung						
$\bar{X} \pm SD$	BDC (2)	BDC	BDC (2)	BDC	BDC (1)	NA
Range	BDC – 0.3	BDC	BDC – 0.5	BDC	BDC – 0.59	

BDC = Below detectable concentration.
NA = No analysis.
#One sample excluded (see text).
* = Number above detectable concentration.

Table 5. Concentration of transuranic radionuclides and ^{90}Sr in tissues of control mallard ducks.

	mBq g^{-1} dry (x 27 = fCi g^{-1})					
	^{238}Pu	$^{239,240}Pu$	^{241}Am	^{242}Cm	^{244}Cm	^{90}Sr
Bone (N = 3)						
$\bar{X} \pm SD$	0.51 ± 0.39	0.66 ± 0.45	0.20 ± 0.16	BDC	0.48 ± 0.14	1120 ± 1910
Range	0.27 – 0.96	0.36 – 1.2	BDC – 0.4	BDC	0.32 – 0.59	17 – 3330
Bone (N = 4)*						
$\bar{X} \pm SD$	BDC	BDC	BDC	BDC	BDC	25 ± 32
Range						7 – 72
Liver (N = 2)						
$\bar{X} \pm SD$	BDC	BDC	BDC	BDC	BDC	1.7 ± 1.2
Range						0.8 – 2.6
Lungs (N = 2)						
$\bar{X} \pm SD$	BDC	BDC	BDC	BDC	BDC	5.0 ± 2.4
Range						3.3 – 6.7
Muscle (N = 3)						
$\bar{X} \pm SD$	BDC	NA	NA	NA	NA	1.0 ± 0.3
Range						0.7 – 1.3

BDC = Below detectable concentration.
NA = No analysis.
*Analyzed by Radiological and Environmental Sciences Laboratory. All other samples analyzed by commercial laboratory.

four mallards collected at the same control location in a subsequent year and analyzed by our laboratory (ESL). Since the commercial laboratory analyzed the control samples along with the experimental samples, cross-contamination may have resulted in positive transuranic concentrations in the control bone tissues.

The transuranic concentrations in bone tissues from mallards immediately sacrificed (Table 3) were similar to control data and less than results from mallards maintained in cages for 51 d after leaving the ponds. Therefore, the transuranic data from bones in Table 3 were suspect. All spiked and control samples were submitted with the second group of samples (Table 4) and none were submitted with the tissues taken from mallards immediately sacrificed after leaving the pond. Therefore, transuranic concentrations in bones of mallards maintained in cages for 51 d (Table 4) were used in subsequent dose and export calculations. All other concentration data used in dose and export calculations were taken from mallards immediately sacrificed after leaving the pond (Table 3). Transuranic concentration data for bone tissue from one mallard maintained in a cage for 51 d after removal from

Table 6. Dose equivalent received by a hunter from consumption of ^{90}Sr and transuranics in one contaminated waterfowl from the Test Reactor Area Ponds.

Nuclide(s) Tissue Consumed	Dose Equivalent Received by Hunter uSv (mrem)		
	Committed Dose Equivalent		Effective Dose Equivalent
	Bone Surfaces	Red Marrow	
Transuranics			
Liver	0.46 (0.046)	0.04 (0.004)	0.03 (0.003)
Muscle	*	*	*
^{90}Sr			
Liver	2.00 (0.200)	0.91 (0.091)	0.17 (0.017)
Muscle	3.03 (0.303)	1.38 (0.138)	0.26 (0.026)
Transuranics and ^{90}Sr			
Liver	2.46 (0.246)	0.94 (0.094)	0.20 (0.020)
Muscle	3.03 (0.303)	1.38 (0.138)	0.26 (0.026)
TOTAL	5.50 (0.550)	2.32 (0.232)	0.46 (0.046)

*Concentration in duck tissue not detectable.

the pond was up to 100 times higher than the remaining samples. The reason for elevated concentrations in this sample is unknown.

Potential dose to man due to consumption of the entire muscle and liver mass of one average-weight duck containing both transuranic and ^{90}Sr was 0.46 μSv (0.046 mrem), 56% of which was from consumption of the muscle and 44% from consumption of the liver (Table 6). The organs receiving the greatest committed dose equivalent were bone surfaces and red marrow, at 5.5 μSv (0.55 mrem) and 2.3 μSv (0.23 mrem), respectively.

The mean dose rate to experimental ducks on the TRA ponds was 0.69 mGy d^{-1} (69 mrad d^{-1}) from ^{90}Sr and transuranic nuclides in body tissues. Strontium-90 in the bone accounted for 97% of this dose rate.

Transuranic nuclide concentrations in the experimental duck GI tracts were compared to concentrations reported in selected ecosystem components of the TRA ponds which could be ingested by the animals (Table 1). Although transuranic data for these ecosystem components were collected at different time periods (June–August) than the duck tissues, transuranic concentrations have been demonstrated to remain relatively consistent through time for changing abiotic and biotic conditions in these ponds (Kuzo et al. 1983). In general, transuranic concentrations in duck GI tract (dry weight) were 10^2–10^3 times greater than filtered water concentrations, 10^3 times less than dry weight concentrations in periphyton, 10–10^2 less than dry weight concentrations in plankton and to 1–10^2 more than vegetation collected from the littoral area (Kuzo et al. 1978, Kuzo et al. 1983). Depending upon the order and life stage of insects, concentrations in duck GI tissue samples were 10 times more to 10^2 times less than littoral insects (Kuzo et al. 1978). Similar concentration data for ^{90}Sr in potential food sources were not available. The concentration of transuranic nuclides from these potential food sources most likely would have been diluted in the GI tract with the food supplement fed to the experimental animals or with food taken outside of the immediate pond environment. However, we never observed the ducks outside the contaminated area which includes the sparsely vegetated banks of the ponds. It is likely that wild ducks use the TRA ponds primarily as a resting area (Halford et al. 1981), obtaining most of their food from agricultural fields and/or larger bodies of water.

The experimental mallards contained an average transuranic body burden of 15.2 Bq (0.41 nCi) when removed from the TRA ponds. This calculation was based upon average transuranic radionuclide tissue concentrations and average mass of bone, GI tract, feathers and liver. Muscle did not have detectable concentrations of transuranic radionuclides. Three thousand one hundred forty-one individuals representing 22 species of waterfowl were observed on the TRA ponds from January 1974 through March 1978 (Halford et al. 1982). If each of the 3141 waterfowl had transuranic concentrations equal to the averages in the experimental waterfowl, 48 kBq (1300 nCi) of transuranics would have been removed during this period, or an annual average of 11.3 kBq (305 nCi). Approximately 75%, 18%, 6% and 1% (52%, 35%, [illegible] and 2% if the one bone sample that was approxim 100 times the other samples was excluded from the erage) of the total transuranic activity in the ducks were associated with bone, feathers, GI tract and liver, respectively. Comparable data for ^{90}Sr do not exist since ^{90}Sr data were not obtained for GI and feather tissues. However, based upon concentrations in bone, muscle, liver and lungs, a total of 3.5 kBq (93 nCi) per duck was present in the experimental ducks. Therefore, if the 3141 individuals in the wild population had similar activity, a total of 11 MBq (292 μCi) of ^{90}Sr would have been exported in the 51-mo period or an annual average of 2.5 MBq (68.7 μCi).

DISCUSSION

The mean potential effective dose equivalent to a person consuming one experimental duck was only 0.03 μSv (0.003 mrem) from the transuranic radionuclides and 0.43 μSv (0.043 mrem) from ^{90}Sr. The calculation of this dose equivalent was based on consumption of an experimental mallard which had been maintained on the ponds for 43–145 d. Estimated residence time of the 3141 wild waterfowl observed on the ponds from January 1974 through March 1978 ranged from less than 1–25 d and averaged 6 d (Halford et al. 1982). Concentrations of γ-emitting radionuclides in tissue from these experim ducks used in this study were greater than concentrat in 28 wild waterfowl collected at the ponds (Halford et al. 1981, Halford et al. 1983). This difference most likely was related to the additional time on the ponds by the experimental ducks. The biological half-times of nine of the γ-emitting radionuclides in ducks from the ponds were determined to vary from 10–86 d (Halford et al. 1983). Therefore, the concentrations in the experimental ducks were closer to equilibrium values than concentrations in wild ducks. Although the biological half-times of transuranic and ^{90}Sr radionuclides in ducks are unknown, it is likely that the experimental ducks also had higher concentrations of transuranics than would be expected to be in the wild duck population due to differences in resident times which would allow more time for the experimental ducks to reach equilibrium. Therefore, transuranic and ^{90}Sr concentrations in the wild ducks and potential dose commitments to people consuming the tissues of ducks would likely be less than concentrations and potential dose commitments calculated from the experimental ducks.

The potential dose equivalent commitment from both transuranic and ^{90}Sr radionuclides to man consuming tissues of these experimental ducks was much lower than the average of 0.12 mSv (12 mrem) whole body and 0.07 mSv (7 mrem) thyroid [or an effective dose equivalent of 0.12 mSv (12 mrem)] from eating the muscle and li[illegible] of one of the wild ducks at the TRA ponds with av concentrations of γ-emitting radionuclides (Halford 1981). This lower dose for transuranic and ^{90}Sr nuclides

is due primarily to the lower uptake and deposition of ese radionuclides in edible tissues.

In the mid-1970s, waterfowl were estimated to export approximately 18.5 kBq (500 nCi) of Pu annually from U Pond at the Hanford Reservation (Emery et al. 1978). Our conservative estimate was that 11.3 kBq (305 nCi) of transuranic radionuclides could have been exported annually by waterfowl using the TRA pond from January 1974 through March 1978 if each of the 3141 waterfowl observed during this period had contained concentrations similar to the experimental ducks. The transuranic activity potentially exported is less than 0.03% of the 37 MBq (1 mCi) γ-emitting activity annually exported by the wild waterfowl at TRA (Halford et al. 1981). The maximum export of 2.5 MBq (68.7 μCi) ^{90}Sr in bone, muscle, liver and lung tissues of ducks is higher than the potential transuranic export by ducks but is lower than the γ-emitting activity potentially exported by waterfowl.

Waterfowl at the TRA ponds potentially export greater quantities of transuranics from this area than do other species of wildlife. The maximum yearly export of transuranic radionuclides by small mammals and coyotes at the TRA was 1.4 Bq (35 pCi) (Halford in press) and 2.6 kBq (70 nCi) (Arthur and Markham 1982), respectively. Larger numbers of waterfowl visit the area than do small mammals or coyotes. Coyotes were likely contaminated through consumption of small mammals, birds and other fauna near the ponds (Arthur and Markham 1982).

In 1981, free ranging small mammals were captured in areas adjacent to the water at TRA and primarily in a dry pond adjacent to the ones containing water (Halford in press). The soil in this dry leaching pond was also contaminated with the five transuranic radionuclides; however, the gravely floor of the dry leaching pond precluded burrowing. Total concentration of these transuranic radionuclides in the mice averaged 10.7 mBq g^{-1} dry (0.3 pCi g^{-1}). For comparison, the average total transuranic radionuclide concentrations in ducks was 38.9 mBq g^{-1} (1.1 pCi g^{-1}). The transuranic nuclides were distributed differently between the two animal groups. About 89% of the transuranic contamination in and on the small mammals was due to contamination of the external tissues (GI tract and pelt), while only 23% (46% if the one bone sample with the highest concentration is deleted from the average) of the transuranic activity in the ducks was associated with external tissues (GI tract and feathers).

The total average concentration of ^{238}Pu and ^{239,240}Pu in the GI tract of the experimental ducks was 0.063 Bq g^{-1} (1.7 pCi g^{-1}). Results of an experiment conducted at the Hanford Reservation where eight ducks (*Anas* sp.) were held in cages on U Pond for two to five days then analyzed for Pu suggest that GI tracts of ducks could have accumulated about 2.6 Bq g^{-1} (70 pCi g^{-1}) of Pu (Emery et al. 1978). The amount of Pu in the GI tract of the ducks at Hanford comprised more than 95% of the total body burden. In contrast, our data indicated only 6% of the total transuranic body burden was associated with the GI tract. The ducks in the Hanford experiment were fed contaminated floc from U pond, which is decomposing algae and macrophytes (Emery et al. 1978). Apparently the ducks could not survive on this diet as those not collected by day five began to die.‡ Most likely there was insufficient time for uptake and deposition in the tissues or perhaps lack of nutrient intake prevented normal uptake and accumulation of transuranic nuclides. Ducks in our study habituated well to the experimental conditions and had more time than those in the Hanford experiment to accumulate transuranics on/in tissues. In addition, chemical forms of the radionuclides could have been different between the two studies. In the ducks at INEL, which were sacrificed immediately after being taken from the ponds, only concentrations in feather and liver tissues were related to time on the ponds. For all five transuranic nuclides, individual concentrations from 145 d ducks > 75 d > 43 d. One duck which was on the pond for 145 d and then placed in a cage for 51 d also had higher concentrations in liver than did the six ducks held in cages for 51 d after being on the ponds 68 or 75 d. This may indicate, that at least for some tissues, the ducks were not on the ponds long enough for the transuranic concentrations in these tissues to be in equilibrium with concentrations in the pond environment.

Gamma-emitting radionuclides in the tissues of wild ducks collected on the TRA pond provided a total average dose of 7.0 mGy d^{-1} (700 mrad d^{-1}) to each duck (Halford et al. 1982). The radiation dose rate to these waterfowl from γ-emitting external sources in the pond environment averaged 0.80 mGy d^{-1} (80 mrad d^{-1}). In comparison, the total radiation dose rate to each duck provided by the transuranics and ^{90}Sr in the tissues was 0.69 mGy d^{-1} (69 mrad d^{-}). Since retention times for transuranic and ^{90}Sr in these waterfowl were unknown, total committed doses to ducks were not calculated. If loss rates for ^{90}Sr were equal to those for most γ-emitting nuclides in ducks (Halford et al. 1983), ^{90}Sr could provide committed doses comparable to that due to γ-emitting nuclides.

Since waterfowl are mobile and are a game species, it is possible that contaminated birds could be harvested and consumed by hunters. However, the TRA leaching ponds are on the INEL, which is closed to hunting. Therefore, potential for wild waterfowl to be contaminated with radionuclides at TRA and to be subsequently harvested by sportsmen is low. During previous studies, we determined that an average of six contaminated ducks per year from TRA could be harvested by Idaho sportsmen (Halford et al. 1981). Potential radiation dose commitments to individuals and the general population from consuming ducks contaminated with transuranics and ^{90}Sr are low and would represent a small fraction of the yearly radiation dose equivalent for individuals from naturally occurring sources of radioactivity in southeastern Idaho (1.49 mSv y^{-1}; 149 mrem y^{-1}) or other sources of external radiation such as medical x-rays and air flights (Halford et al. 1981). Strontium-90 and transuranic nuclides in

‡ Klopfer, Donald. Personal Communication, Battelle Pacific Northwest Laboratory, Richland, WA 99352.

duck tissues from TRA ponds appear not to be a significant health hazard to man consuming the tissues of these waterfowl since they would provide less than 0.05% of the effective dose equivalent limit of 1.00 mSv y^{-1} (100 mrem y^{-1}) for continuous operations at DOE fac (U.S. DOE 1985).

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